Final Focus and Beam Delivery for Advanced Colliders

Spencer Gessner

Snowmass Agora on Advanced Colliders

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U.S. DEPARTMENT OF ENERGY | Stanford University

SLAC NATIONAL ACCELERATOR LABORATORY

Collider Luminosity

Geometric Luminosity

$$\mathcal{L} \propto \frac{f N_b^2}{\sigma_x \sigma_y}$$

Beamstrahlung Luminosity

$$\mathcal{L} \propto \frac{n_\gamma^{3/2}}{\sqrt{\sigma_z}} \frac{1}{\sigma_y} \frac{P_b}{E_b}$$

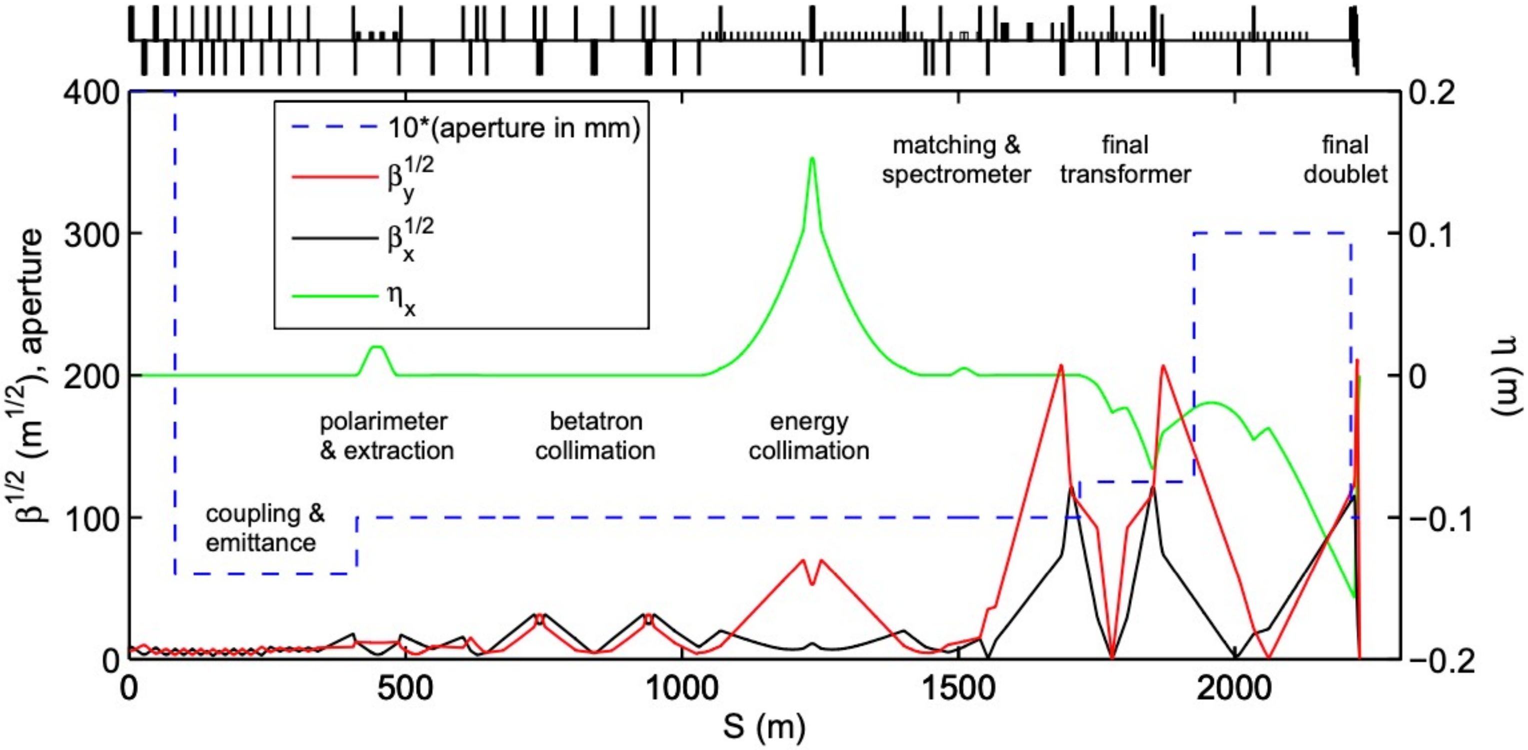
The luminosity formula reflects the “values” of the collider.

Values of a Linear Collider

- Precision!
  - The Linear Collider "complements" the hadron collider.
  - Maximize $\mathcal{L}_{0.01} \rightarrow$ Minimize n_γ
- Clean Environment
  - Collimation is critical.

For CM Energies < 3 TeV, Advanced Colliders have the same "values" as traditional Linear Colliders

Traditional BDS



ILC TDR: https://arxiv.org/abs/0712.2361

Targets for Improvements

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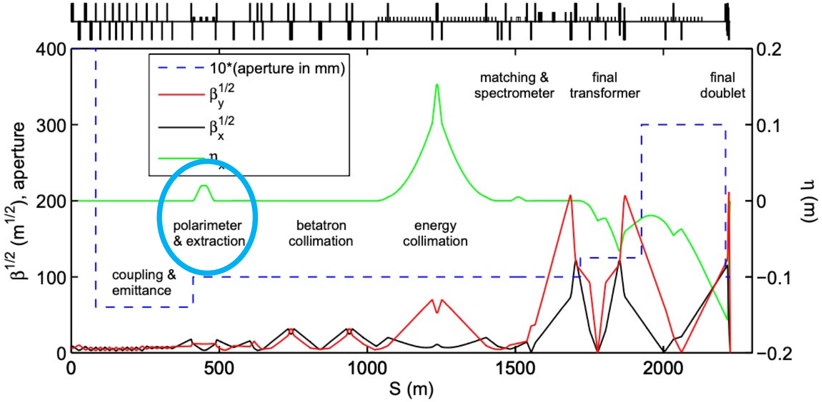
- The key figure of merit is luminosity per beam power.
    - Advanced Accelerators use short bunches → Factor of 8 improvement over ILC.

$$\frac{\mathcal{L}}{P_b} \propto \frac{n_\gamma^{3/2}}{\sqrt{\sigma_z}} \frac{1}{\sigma_y} \frac{1}{E_b}$$

- Can specific parts of the BDS system be improved upon?
    - E.g. emittance measurement with betatron radiation.



Challenges for AAs and Traditional BDS

- Large transverse wakefields accompany large accelerating wakefields.
  - Mitigated by BNS damping, which implies percent-level energy spread.

- Traditional (New!) Final Focus has subpercent-level acceptance.

Chen, Schulte, Adli, *J. Phys.: Conf. Ser.* **1596** 012057 (2020)

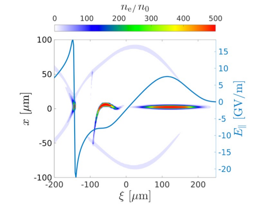


Figure 5. Electron number density n_e per unit initial plasma density n_0 and the total longitudinal electric field $E_\parallel(\xi)$ for $s \approx 140$ cm obtained from QuickPIC simulation with Snowmass parameters. The plasma electron density has been increased by a factor 10 in order to highlight the bubble boundary.

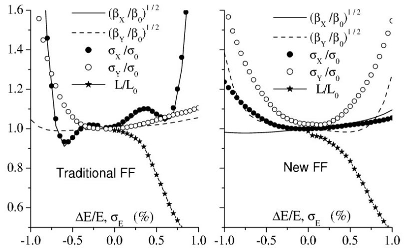


FIG. 4. IP bandwidth of the traditional and the new NLC final focus. Normalized betatron functions and normalized luminosity equivalent beam size versus energy offset $\Delta E/E$, and normalized luminosity versus rms energy spread σ_E.

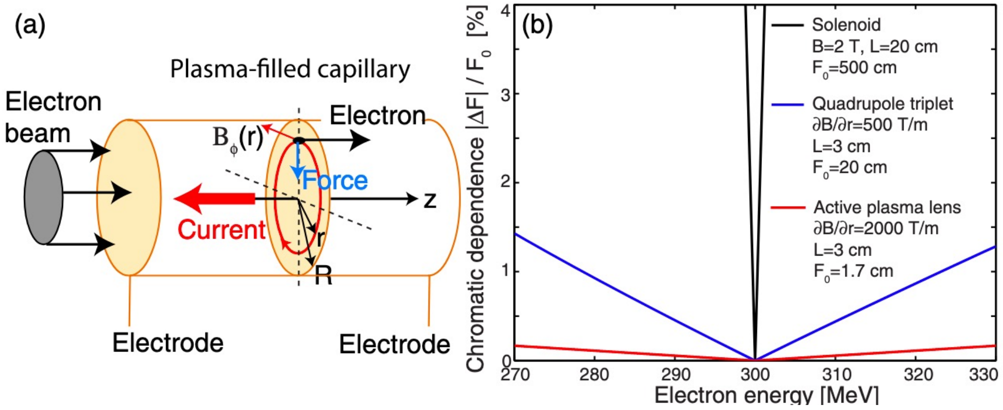
P. Raimondi and A. Seryi, Phys. Rev. Lett, 86, 3779 (2001)

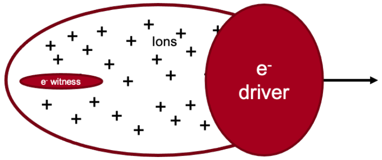
Plasma Lens Solutions

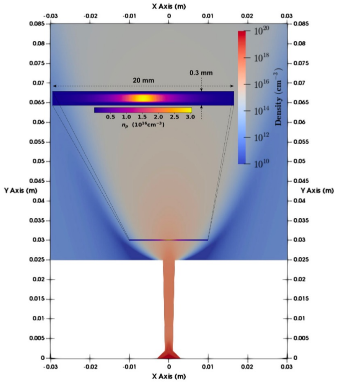
Plasma lens systems offer two main advantages:

1. Focusing gradients are orders of magnitude larger than what can be achieved with traditional systems.
2. Axisymmetric focusing strongly reduces chromatic effects.

J. van Tilborg et. al., PRL115,184802 (2015)







C. Doss et. al., PRAB 22, 111001 (2019)


Beyond 10 TeV

Values of an Energy Frontier Collider

- Discovery!
    - A 100 TeV hadron collider and a 15 TeV lepton collider have similar reach.
- Maximize $\mathcal{L}$!
    - But sacrifice precision. . .

Parameter Tables

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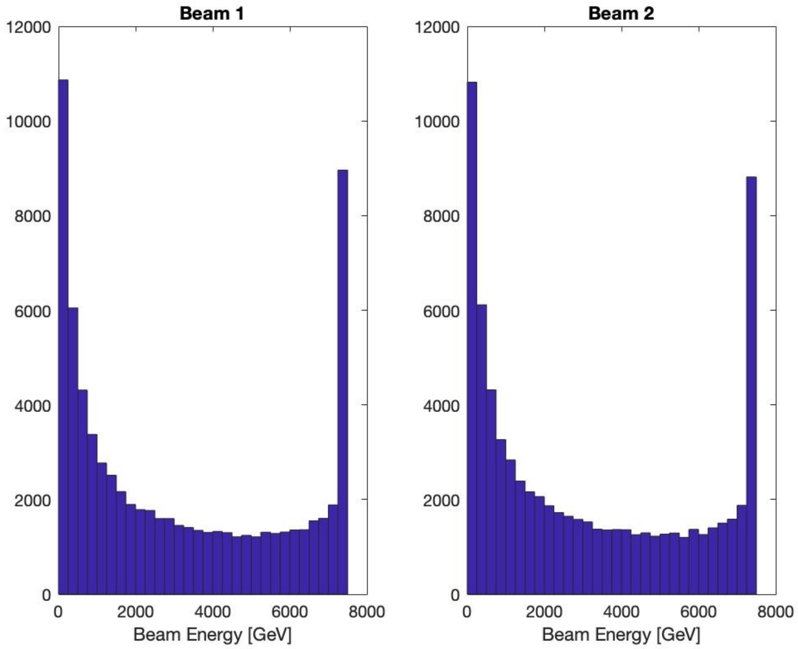
- At 1 TeV and 3 TeV, we adopt "CLIC-like" parameters with an eye on precision.
- At 15 TeV, we assume round beams for the collisions.

	PWFA 1 TeV	PWFA 3 TeV	PWFA 15 TeV
Single beam energy (TeV)	0.5	1.5	7.5
Gamma	9.78E+05	2.94E+06	1.47E+07
Emittance X (mm mrad)	0.66	0.66	0.1
Emittance Y (mm mrad)	0.02	0.02	0.1
Beta* X (m)	5.00E-03	5.00E-03	1.50E-04
Beta* Y (m)	1.00E-04	1.00E-04	1.50E-04
Sigma* X (nm)	58.07	33.53	1.01
Sigma* Y (nm)	1.43	0.83	1.01
N_bunch (num)	5.00E+09	5.00E+09	5.00E+09
Freq (Hz)	4200	1.40E+04	2575
Sigma Z (um)	5	5	5
Beamstrahlung param	1.49E+01	7.76E+01	6.59E+03
n_gamma	1.49E+00	1.49E+00	5.75E+00
Single Beam Power (MW)	1.7	16.8	15.5
Two Beam Power (MW)	3.4	33.6	30.9
Geo. Lumi (cm^-2 s^-1)	1.01E+34	1.01E+35	5.01E+35
Beamstrahlung lumi	1.99E+34	1.99E+35	5.07E+35
Wall plug to drive laser/beam eff	0.4	0.4	0.4
Laser/beam drive to main eff	0.375	0.375	0.375
Site power Wall to main only (MW)	22.4	224.3	206.3
Lumi/Power (1e34/MW)	0.04	0.04	0.24

Beamstrahlung Effects

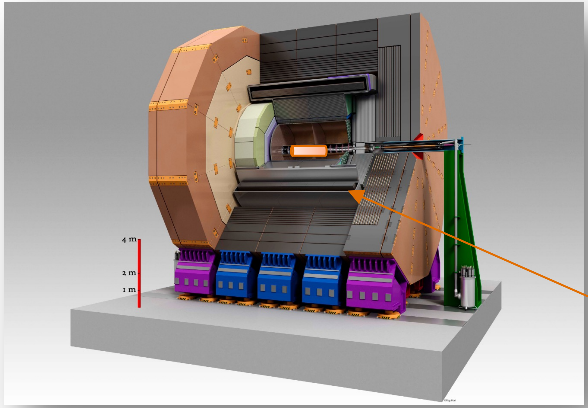
- Large n_γ means large energy spread beams.
  - Reduced $\mathcal{L}_{0.01}$

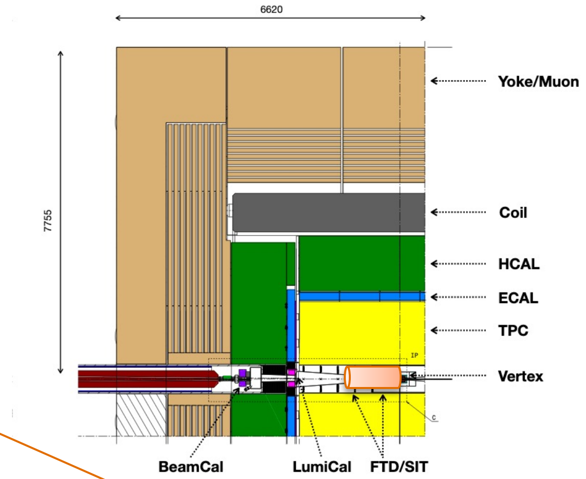
- Practical challenges for transporting beams to dump!

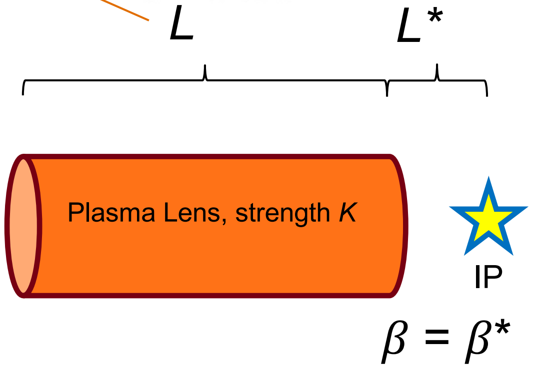


GUINEA-PIG Simulation by G. Cao, Univ. Oslo

Taking Advantages of Plasma Lenses







In order to take *full* advantage of the plasma lens, it must be close to the IP.

Challenges of Advanced BDS

- Small, round beam emittances (sub micron) demonstrated in plasma injector experiments with electron beams.
  - How do we create small round beam emittances for positron beams?
- Passive plasma lenses work for electron beams, but (naively) not for positron beams.
- How do we transport high energy spread beams from IP to dump?
  - Large crossing angle at IP?